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A *ROSAT* HRI observation of 3C 356: further evidence for a distant intracluster medium

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ABSTRACT

We report a 36-ks *ROSAT* HRI observation of the distant powerful radio galaxy 3C 356, which was detected in the PSPC. No point source is detected at the position of the radio galaxy at the flux expected from the PSPC observation, confirming that the PSPC source is extended. A weak extended source is detected in the HRI. We therefore rule out interpretations of the X-ray emission from this source as originating from the active nucleus, or a jet–cloud interaction. The emission observed with the PSPC most plausibly originates from the most distant intracluster medium yet detected in X-rays.

Key words: galaxies: active – cooling flows – galaxies: individual: 3C 356 – radio continuum: galaxies – X-rays: galaxies.

1 INTRODUCTION

We have earlier reported the detection of the powerful radio galaxy 3C 356 with the *ROSAT* Position Sensitive Proportional Counter (PSPC) (Crawford & Fabian 1993). At a redshift $z=1.079$, it is the most distant yet reported in the literature. Powerful radio galaxies tend to occur in clusters of galaxies (Yates, Miller & Peacock 1989; Hill & Lilly 1991) and so should mark the sites of distant clusters. The active nucleus of the radio galaxy should be highly absorbed and hence undetectable by *ROSAT*. The most probable source for the observed X-ray emission is thus the intracluster medium of a host cluster of galaxies. The luminosity of the source associated with 3C 356 is $\sim 2.5 \times 10^{44}$ erg s^{-1} (0.2–2 keV in our frame; we adopt $H_0=50$ km s^{-1} Mpc^{-1} and $q_0=0.5$), and the ~ 30 count detected in 18 565 s were spread over the *ROSAT* energy band, indicating that the source is certainly not heavily absorbed, and is consistent with an intracluster medium at a temperature of about 4 keV. The source was too faint to search for any spatial extent in the PSPC image.

This interpretation has been disputed by Lacy & Rawlings (1994), who propose a precessing, interacting jet model to explain the high ionization of one of the central optical components. This model requires that the X-rays originate from a jet–cloud interaction, and predicts that the X-ray source is point-like at the resolution of the High Resolution Imager (HRI). Our intracluster medium interpretation predicts an extended X-ray source. We have therefore carried out a follow-up observation with the *ROSAT* HRI in order to eliminate the possibility that a point-like X-ray source has been detected.

The central galaxy of 3C 356 has not been conclusively identified, since there are two faint objects 5 arcsec apart close to the centre of the radio lobes, both of which are faint radio sources (Fernini et al. 1993). Lacy & Rawlings (1994) propose that the southern object is the origin of the ratio lobes, whereas Best, Longair & Röttgering (1996) prefer the northern one since in *Hubble Space Telescope* (*HST*) imaging it shows a dust lane similar to that seen in other 3CR galaxies. We designate them here as 3C 356N and S (Lacy & Rawlings 1994 denote them a and b, respectively).

2 THE *ROSAT* OBSERVATIONS

3C 356 was observed with the *ROSAT* HRI for 36 379 s between 1995 April 7 and 9. No point source is detected at the position of 3C 356N, with a 3σ limit of ~ 7 count. The limit is less strong for 3C 356S since there is a weak peak in the X-ray image (Fig. 1) about 5 arcsec to the south with 12 ± 5 count (the full width at half-maximum intensity for the HRI is about 5 arcsec). Based on the PSPC detection, we expect 20 ± 4 count in the HRI. (We have used the software package PIMMS to make this estimate; it takes into account the differing spectral responses of the HRI and PSPC.) The absolute pointing accuracy of *ROSAT* with the HRI is such that 'most known objects are detected within 10 arcsec of the catalogue positions' (David et al. 1993). We conclude that, unless an improbable combination of point-

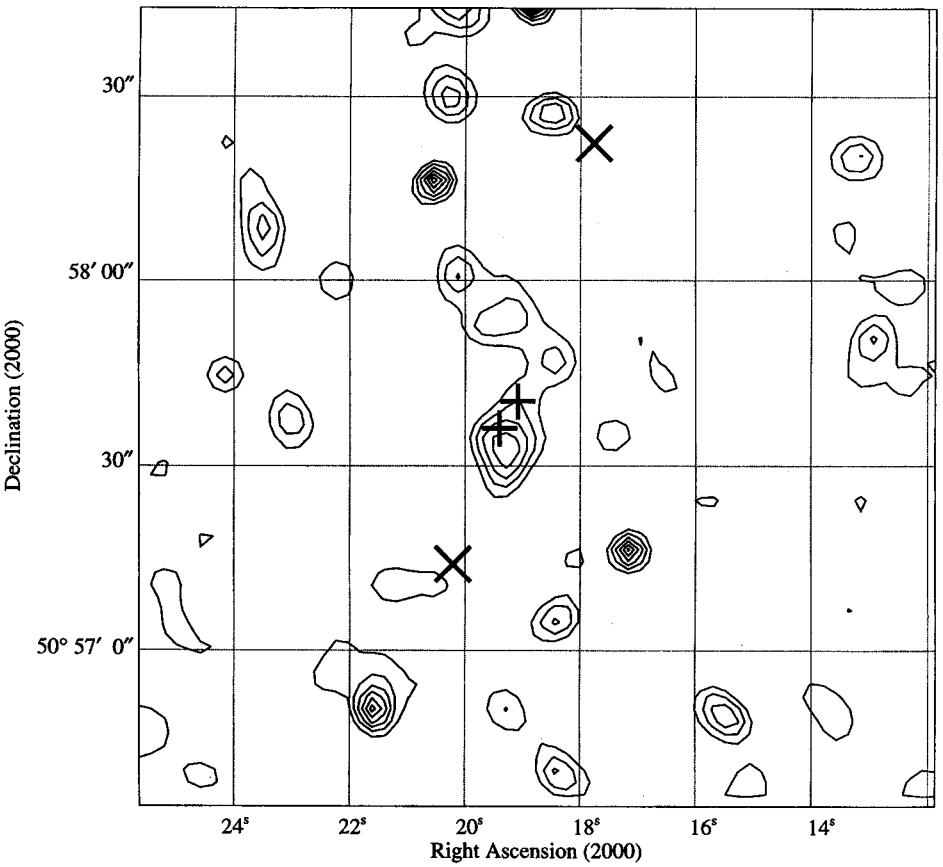

Figure 1. Contour map of the HRI image at the position of 3C 356. The X-ray image was binned in 2-arcsec pixels and smoothed. The crosses indicate the positions of the radio lobes and the pluses the positions of the two central optical/radio components, 3C 356N and S (see Fernini et al. 1993). None of the X-ray peaks represents a statistically significant excess above background at the 3σ level; there is an extended excess around 3C 356N significant at a level corresponding to 98 per cent confidence (see text).

ing inaccuracy and count detections has occurred, less than about one-third of the flux detected by the PSPC can originate in a compact source at 3C 356N. Our result is marginally consistent with a point source at the position of 3C 356S. The simplest explanation is that the PSPC source is extended. Although it is possible that the source is variable, we consider it highly unlikely for such a powerful radio galaxy.

We have attempted to check the pointing accuracy using the only source actually detected in the HRI field. It lies to the north-north-west of the radio galaxy (not shown in this Fig. 1; it is the upper source in fig. 1 of Crawford & Fabian 1993). It has a similar flux in the PSPC to 3C 356, and is found with the HRI to be a point source (Fig. 2a), demonstrating that the non-detection of any clear point source at the position of 3C 356 is not due to some pointing or tracking error. The HRI source does not coincide with any object in the Digitized Sky Survey or the APM archive. The nearest object is 10 arcsec to the north-north-east. If this is indeed the source then the weak peak at the centre of the HRI image lies 5 arcsec to the east of 3C 356N.

There is, however, a possible weak extended source at the position of 3C 356 in the HRI image (Fig. 1). We find that there are ~ 24 count (background-corrected) within a large detection box (44-arcsec width), and the probability that these are due to a chance fluctuation (at that position) is about 1.5 per cent. The background-corrected profile centred on the position of 3C 356N is shown in Fig. 2(b), and is compared with that expected from a point source with the expected 20 count. This emphasizes that there is not a point source at the flux level predicted by the PSPC detection at this position.

There is no trace of X-ray emission coincident with the radio lobes, which agrees with the PSPC image where most of the X-rays originate from within the region spanned by the radio lobes.

3 DISCUSSION

Our HRI image of the 3C 356 field shows no point X-ray source coincident with the radio galaxy 3C 356N at the level expected from the PSPC detection. The HRI data are well consistent with, and indeed show marginal evidence for, such an extended source. The most plausible origin for the X-ray emission observed with the PSPC is that it is extended and due to an intracluster medium surrounding the radio galaxy, and not an active nucleus or jet–cloud interaction associated with 3C 356N (as proposed by Lacy & Rawlings 1994).

Our results appear marginally consistent with a point source at the position of 3C 356S. It is, however, most unlikely that this object harbours an active nucleus giving

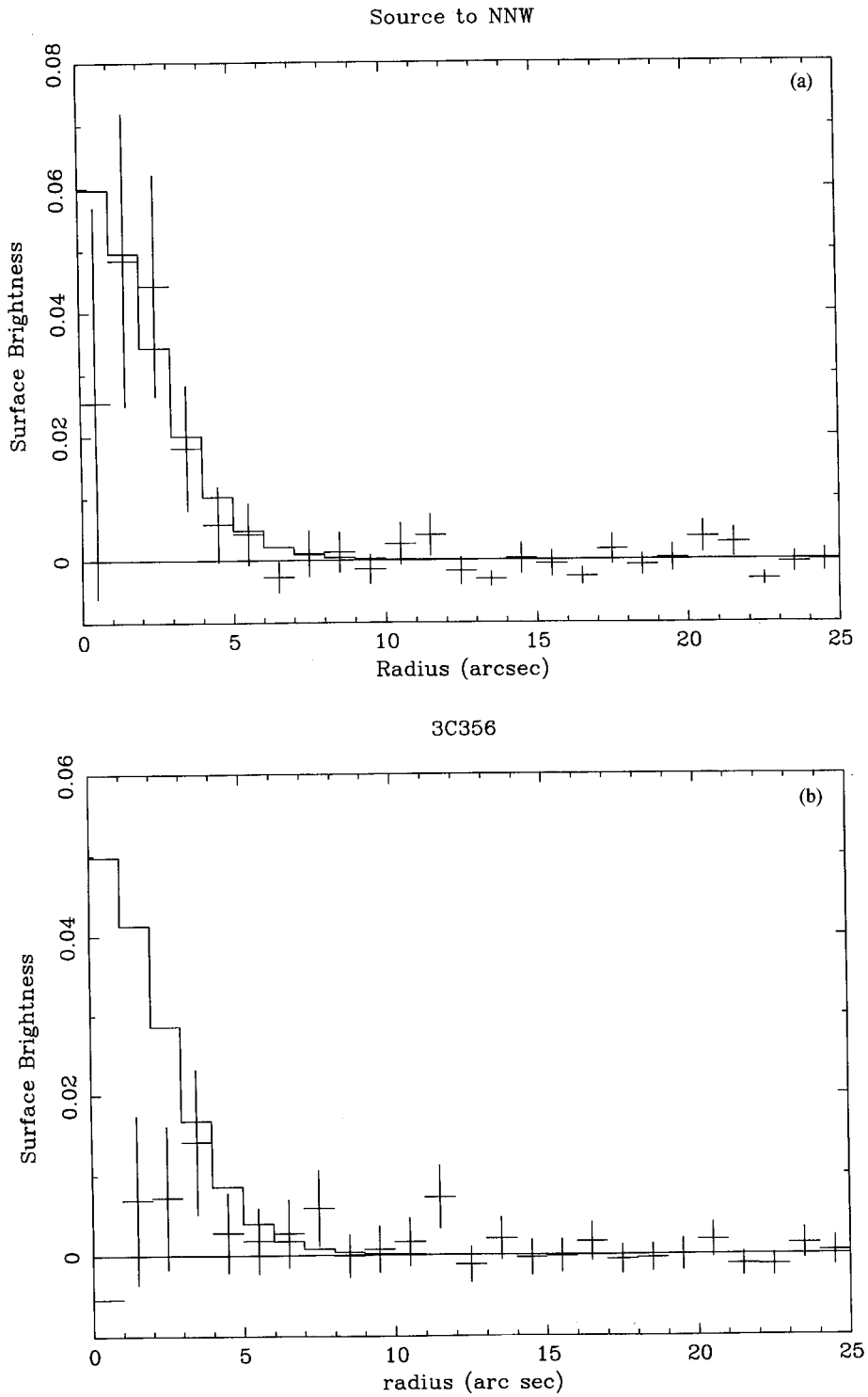

Figure 2. Spatial HRI profiles of (a) the point source north-north-west of 3C 356 and (b) the source centred on 3C 356N. The solid line shows the spatial profile expected from a point source; in (b) it is normalized to give the flux level predicted by the PSPC detection. The units of surface brightness are count s^{-1} $arcmin^{-2}$.

rise to the observed X-ray flux, since (i) soft X-rays below 0.25 keV were detected in the PSPC, indicating that the source is unabsorbed (Crawford & Fabian 1993), and (ii) an unabsorbed nucleus with a typical optical-to-X-ray flux ratio (the energy spectral index for quasars $\alpha_{ox} \sim 1.5$) scaled from the detected X-ray flux would give an optical flux about 100 times greater than that detected by Lacy & Rawlings (1994).

We conclude that the emission observed with the PSPC around the radio source originates from an intracluster medium, the most distant yet detected. The scale relevant to the PSPC (Crawford & Fabian 1993) corresponds to a few

100 kpc, which contains just the cluster core and any cooling flow around the radio source host. On this basis we cannot be specific about the optical richness of the cluster, but scaling the X-ray luminosity to that of nearby clusters would suggest that it is moderately rich (more so than the Virgo cluster, for example).

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